SECRET

Lockheed Aircraft Corporation

CALIFORNIA DIVISION

REPORT NO. SP-150

DATE 30 Dec. '59

COPY NO.

MODEL U-2

TITLE COLD FUEL & RANGE EXTENSION STUDY

25X1

PREPARED BY

APPROVED FOR ENGINEERING ONLY

APPROVED FOR INTERDEPARTMENTAL USE

25X1

APPROVED FOR OUTSIDE AGENCIES (Specific ones!)

REVISIONS

DATE	PAGES AFFECTED

SECRET

FORM

Lockheed AIRCRAFT CORPORATION

CALIFORNIA DIVISION

INTRODUCTION

Detachment C recently proposed the use of pre-cooled fuel to increase the range of the U-2 airplane. A study was made to evaluate the special equipment required, the techniques involved and the performance increase to be expected. The results of this study are reported herein, and recommendations for extending the range of the airplane are presented.

Available performance information from Detachment C was also studied to determine how closely the airplanes are meeting the Flight Handbook performance. The results from this study are included.

Lockheed AIRCRAFT CORPORATION
CALIFORNIA DIVISION

TABLE OF CONTENTS

TITLE	PAGE
INTRODUCTION	1
FIGURE INDEX	2
COLD FUEL	3
Special Equipment and Techniques	
Airplane Performance	
"Manufactured" Fuel	
PERFORMANCE SUMMARY - Detachment C	8
Mission Data	
Mission Summary	
Airplane Comparison	
Pilot Comparison	
Comparison by Date	
CONCLUSIONS	15
RECOMMENDATIONS	16

Lockheed AIRCRAFT CORPORATION

CALIFORNIA DIVISION

FIGURE INDEX

FIGURE	TITLE	PAGE
1	CRUISE PERFORMANCE UTILIZING "Manufactured" Fuel	7
2	DETACHMENT C FUEL vs. TIME Full Slipper Tanks	12
3	DETACHMENT C FUEL vs. TIME Empty Slipper Tanks	13
4.	DETACHMENT C FUEL vs. TIME Full Main, Empty Aux. & Slipper Tanks	14

COLD FUEL

Special Equipment and Techniques

Pre-cooling the fuel would not be satisfactory if the cold fuel was then loaded into a warm airplane. The fuel would absorb heat, expand and a certain amount would be lost overboard. This amount would be unpredictable and make an accurate fuel counter setting impossible.

This leads to a requirement for equipment which would cool the fuel, circulate this fuel through the airplane to cool the tanks and then return the fuel to the cooling unit to remove the heat absorbed from the airplane. It would be necessary to circulate the fuel through the main and auxiliary wing tanks and possibly the slipper tanks. The fuselage sump tank probably would not have to be cooled. Insulating blankets over the wings would be required during this operation.

Such equipment is available. However, it was not designed specifically for fuel cooling and would have to be adapted to our requirements.

Modifications would have to be made to the airplane to permit the fuel to be circulated.

COLD FUEL

Special Equipment and Techniques (cont)

A thorough test program would be required to test the cooling and circulating equipment, develop the best operational procedures, determine the time required for the operation and evaluate the airplane performance.

Airplane Performance

At present, a full slipper tank airplane is loaded with about 10,100 pounds of fuel. This is 1535 gallons at a fuel temperature of 60°Fahrenheit. However, due to "manufacturing", about 3% or 45 gallons is unused because the fuel counter is set at 1535 gallons. The corresponding performance is 10 + 45 hr. and 4500 miles to zero fuel counter indication. However, if we took advantage of the "manufacturing" we would set the totalizer to 1580 at take-off. Our performance would then be 11 + 10 hr. and 4700 miles at zero fuel counter indication and all of the usable fuel would be burned.

If the fuel and the airplane tanks were cooled to zero degrees Fahrenheit, about 10,390 pounds of fuel would be loaded into the airplane. This is a 3% increase in fuel weight. The manufactured fuel would now be about 6% or 90 gallons. To take complete advantage of this the fuel counter would be set to 1625 at take-off, and the performance would be 11 + 30 hrs. and 4850 miles at zero

COLD FUEL

Airplane Performance (cont)

fuel counter indication. Again, all of the usable fuel would be burned at zero fuel indication. Notice that only half of the performance improvement is due to cooling the fuel. The other half is due to resetting the fuel counter. To be conservative and allow for variations in fuel cooling and specific weight it probably would not be advisable to set the fuel counter higher than 1580 gallons. Therefore, the performance would be 11 + 10 hr. and 4700 miles which we can now obtain if we take advantage of the "manufactured" fuel.

"Manufactured" Fuel

The "manufactured" fuel remaining in the U-2 airplane has been proven many times by careful test and was again verified during the recent U-2C development program. This occurs because the fuel is heated by the fuel-oil heat exchanger and engine driven fuel pump to a temperature of about 140° Fahrenheit. The heating expands the fuel so that the volume increases over the volume of fuel placed in the tanks. The fuel counter is set to the number of gallons in the tanks; however, the fuel totalizer meter is located downstream of the engine driven fuel pump and measures the volume of hot expanded fuel delivered to the engine. Since the volume

COLD FUEL

"Manufactured" Fuel (cont)

increase is neglected when the counter is set, there is usable fuel remaining in the tanks after the counter indicates all fuel has been burned.

The volume increase varies with the temperature of the fuel in the tanks. If the airplane is loaded with 100°F fuel, the volume increase or "manufactured" fuel will only be about 1%; with 60°F fuel, the increase will be 3%; with 0°F fuel, the increase will be 6%. This may vary somewhat depending upon the tolerance of the fuel-oil heat exchanger setting.

Figure 1 shows the predicted performance utilizing the "manufactured" fuel. This is based on a fuel temperature of 60°F in the tanks and a take-off fuel counter setting of 1580 gallons.

LOCKHEED AIRCRAFT CORPORATION
CALIFORNIA DIVISION

DATE
CHECKED BY

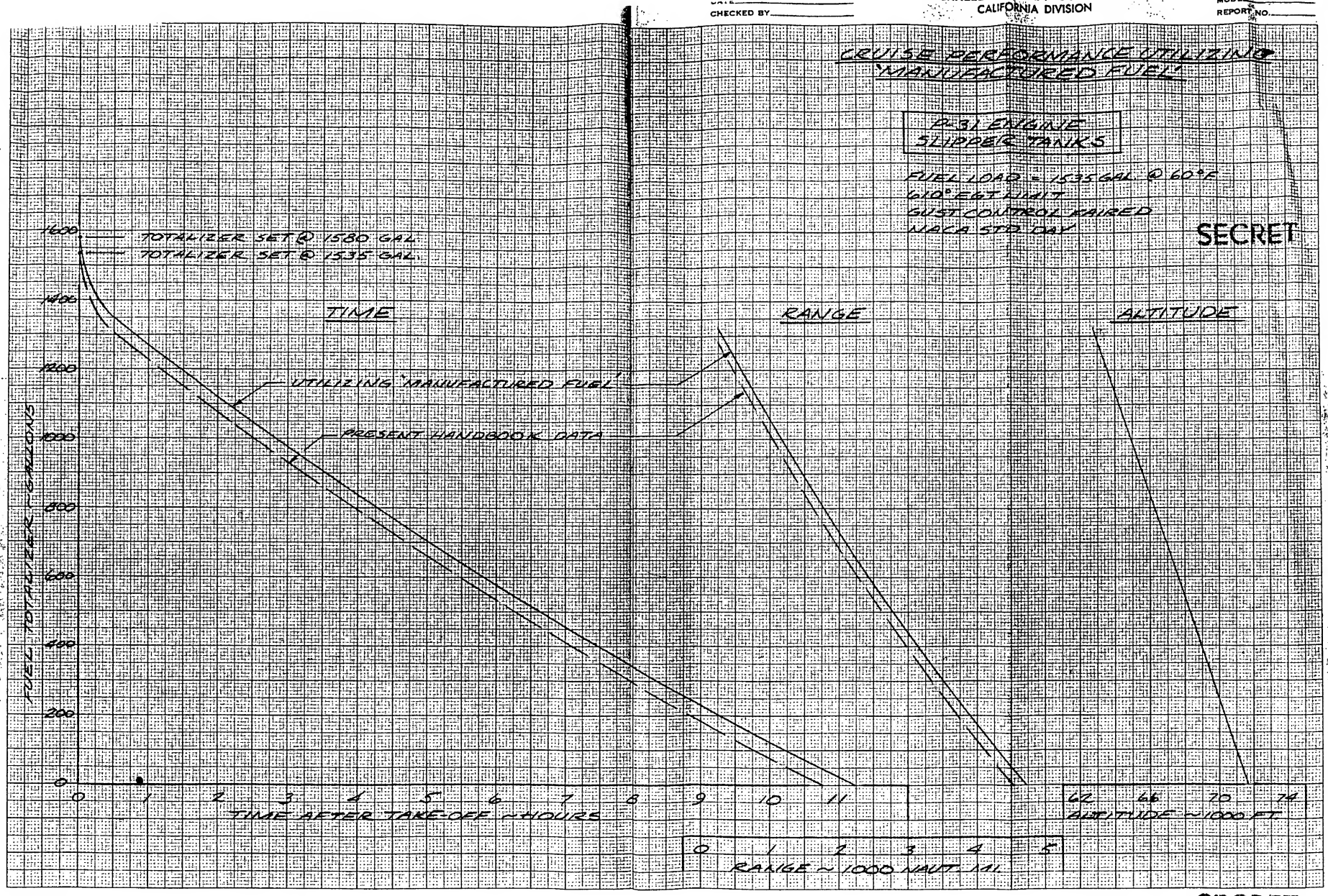
PAGE
MODEL
REPORT NO.

CRUISE PERFORMANCE UTILIZING MANUFACTURED FUEL

R-31 ENGINE
SLIPPER TANKS

FUEL LOAD = 1535 GAL. @ 60°F
610° EGT LIMIT
GUST CONTROL FAIRED
NACA STD. DAY

SECRET



FORM 5278C

FIG. 1 SECRET

PERFORMANCE SUMMARY - Detachment C

A total of 23 missions flown during the period from 15 July 1958 to 16 September 1959 were studied. Practically all missions were with slipper tanks. Where there is some doubt about the configuration this is indicated on the curves.

The performance was studied on the basis of fuel consumption only since no range or altitude data were available. The Flight Handbook performance was considered to have been met if the mission fuel did not deviate more than 1 1/2% below the Handbook fuel versus time curve. This permits the fuel remaining to be about 20 gallons below the Handbook curve for a 10 hour mission. Better agreement than this generally should not be expected under actual operational conditions. In fact, if the Flight Handbook specification MIL-M-7700A were followed, the fuel consumption would be increased 5% to compensate for variations in aircraft and operating techniques. This would allow the fuel remaining to be about 75 gallons below the Handbook fuel-time curve and is obviously over conservative.

Mission Data

The mission data are plotted in Figures 2, 3 and 4. The results are summarized as follows:

Lockheed AIRCRAFT CORPORATION
CALIFORNIA DIVISION

PERFORMANCE SUMMARY - Detachment C

Mission Data (cont)

Performance was generally satisfactory. This conclusion is based primarily on the fact that 18 missions of a duration 6 hours or longer were flown and 13 of these missions met the Handbook performance. Of the 5 that did not meet the Handbook performance one was only 2% below the fuel-time curve.

On an individual airplane basis, all but one met the Handbook performance. However, data were available for only one 4 hour flight on this particular airplane.

A study was made to see if any pilot consistently got better performance; thus indicating possible differences in pilot technique. This did not prove to be the case.

Time of year was studied to see if any effect on performance was obvious. No such trend was indicated.

The following tabulations summarize the performance statistically.

MISSION SUMMARY

NUMBER	DURATION	MET PERF.	MISSED PERF.
18	6 hrs. & longer	13	5 (one only 2% low)
1	5 hr.	0	1
4	4 hr.	1	3

Lockheed AIRCRAFT CORPORATION
CALIFORNIA DIVISION

AIRPLANE COMPARISON

S/N	MET PERF.	MISSED PERF.
441	3	2
425	4	0
170	1	0
342	1	0
401	1	0
353	2	1
378	0	1 (4 hr. Flite)
359	2	5 (one only 2% low)

PILOT COMPARISON

25X1

PILOT	MET PERF.	MISSED PERF.
	3	2
	3	2
	2	2 (one only 2% low)
	2	1
	3	1
	1	1

FORM 97676

Lockheed AIRCRAFT CORPORATION

CALIFORNIA DIVISION

COMPARISON BY DATE

S/N	MET PERF.	MISSED PERF.
441	15 July58 7 Nov. 58 29 Jan. 59	13 Nov. 58 30 Mar. 59
425	20 Aug. 58 11 Oct. 58 7 Nov. 58 (twice)	0
170	20 Aug. 58	0
342	24 Sept. 58	0
401	21 Oct. 58	0
353	3 Sept. 59 5 Sept. 59	29 Aug. 59
378	0	6 Aug. 59 (4 hr. flite)
359	15 May 59 16 Sept. 59	13 May 59 4 June 59 6 Aug. 59 30 Aug. 59 (2% low) 1 Sept. 59

DATE 6/27/57
CHECKED BY

LOCKHEED AIRCRAFT CORPORATION
CALIFORNIA DIVISION

MODEL
REPORT NO

SECRET

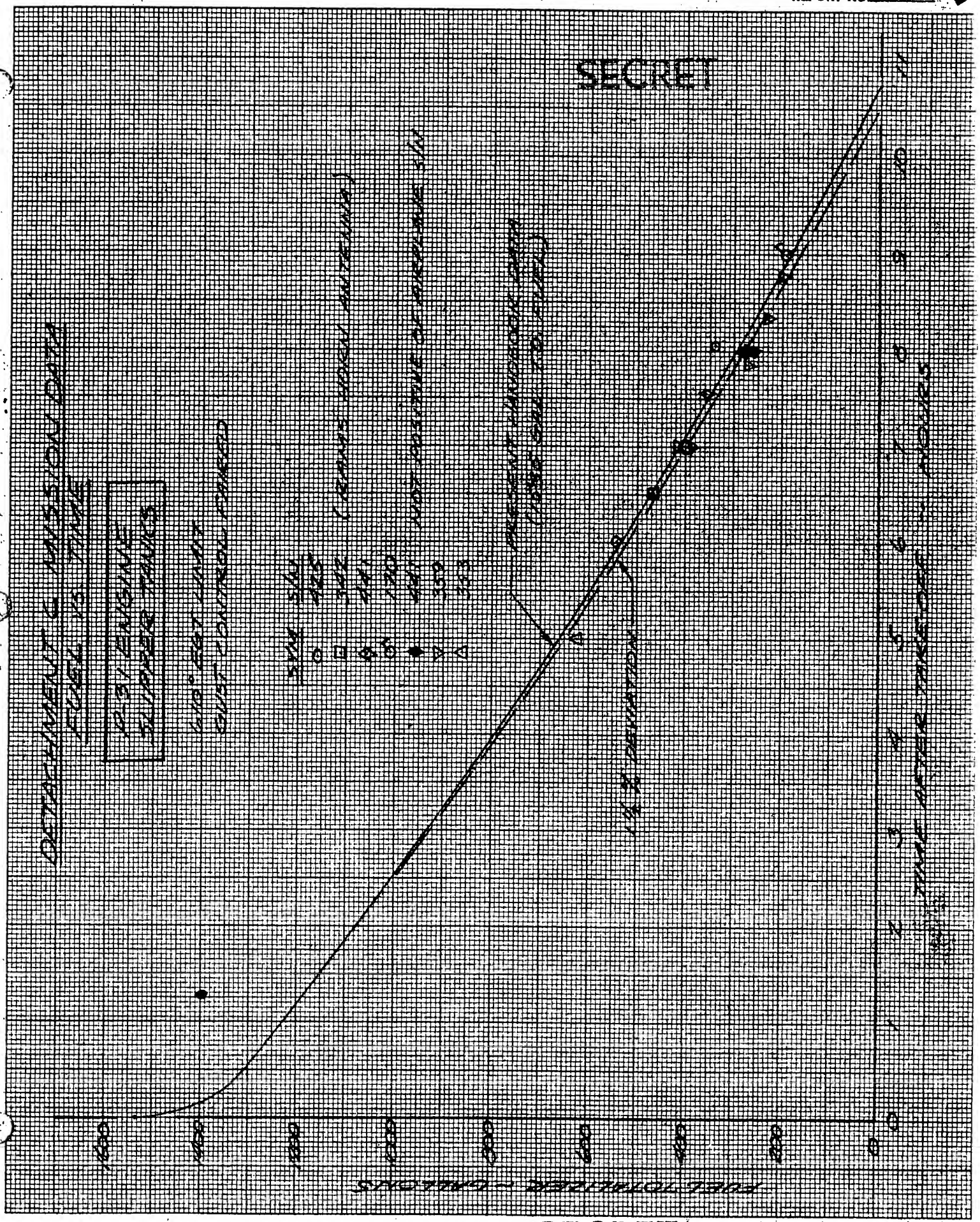


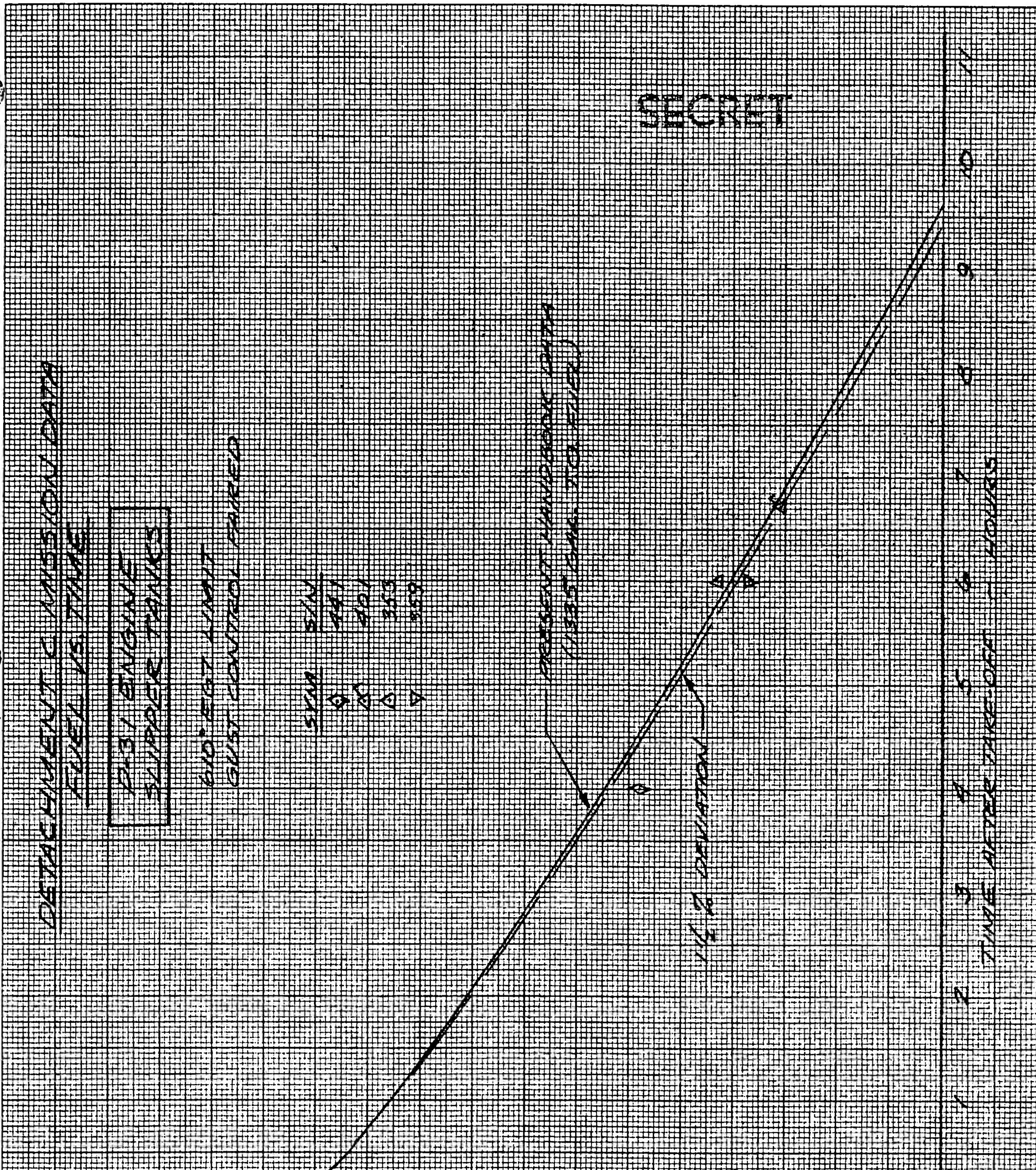
FIG 2

SECRET

FORM 5276A

CHECKED BY ________ CALIFORNIA DIVISION REPORT NO. ________

SECRET



FORM 5278A

FIG. 3

SECRET

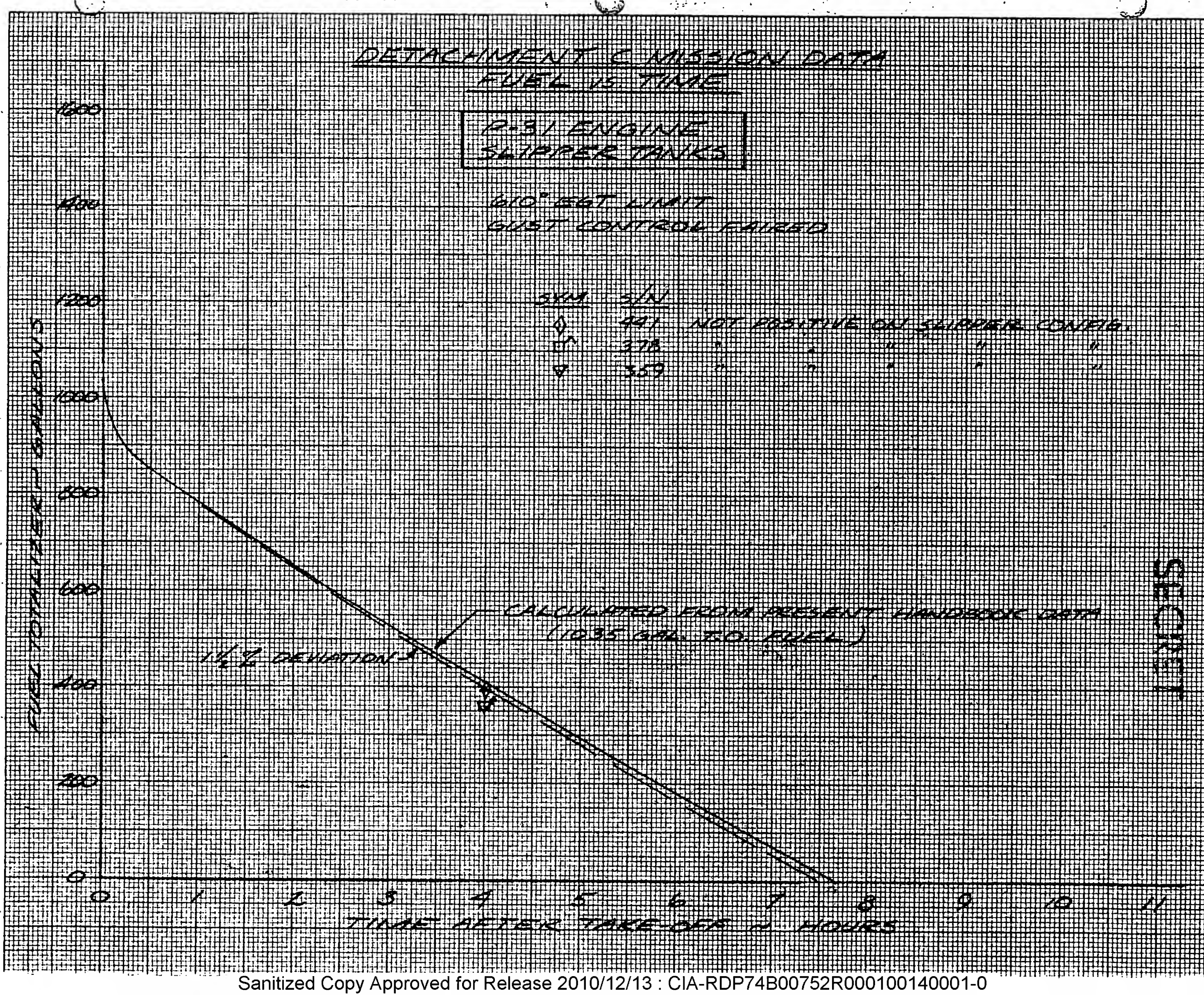


FIG. 4

SECRET

SECRET

FORM 827BA

DATE 12/29/59
CHECKED BY

LOCKHEED AIRCRAFT CORPORATION
CALIFORNIA DIVISION

PAGE
MODEL
REPORT NO.

CONCLUSIONS:

The following conclusions are drawn based on the foregoing cold fuel and Detachment C performance studies.

The airplanes are essentially meeting the Flight Handbook performance and fuel cooling is not required for this purpose.

Fuel cooling would provide a performance increase of about 200 miles and 25 minutes. However, there would probably be wide variations in performance; much more than now exist.

The complications of fuel cooling are hardly justified when we could realize increased performance merely by utilizing the "manufactured" fuel already in the airplane.

RECOMMENDATIONS:

The following recommendations are made if it is considered desirable to extend the U-2 range.

1. Utilize the "manufactured" fuel which is presently in the airplane but is not used. Accomplish this by including the fuel volume expansion factor in the counter setting as shown below.

	FUEL COUNTER SETTING		
Fuel Temp. In Tanks	Full Slippers	Full Internal	Full Mains
20°F	1610	1400	1085
40°F	1595	1385	1075
60°F	1580	1375	1065
80°F	1565	1360	1055
100°F	1550	1345	1045

2. Before doing this, have the detachments verify the existence of the "manufactured" fuel through careful measurement. The following procedure should be used:

   a) Completely drain and fill the sump and wing tanks to determine the actual fuel capacity. This is generally greater than the nominal 1335 gallon capacity.

   b) The draining must be done carefully. The airplane must be tipped to drain the wings. At least 20 to 25 minutes in the tipped position should be allowed for the fuel in one wing to run outboard.

RECOMMENDATIONS (cont)

c) Filling must be done carefully and accurately. A Revere Blue Top flowmeter and counter, known to be accurate, should be used to measure the number of gallons.

d) When the airplane is fueled for a mission measure the fuel temperature in the tanks and the specific weight (lb./gal.). Most electronic weighing kits include the equipment necessary to do this.

e) Use the standard fuel counter setting for take-off; 1535 or 1335 as the case may be.

f) After flight, record the fuel counter reading at engine shut down.

g) Drain all tanks completely to determine the number of gallons remaining in the airplane.

h) Gallons consumed = (e) - (f)

i) Total = fuel consumed + fuel remaining

= (h) + (g)

j) "Manufactured" fuel = total - actual capacity

= (i) - (a)

= $\frac{(i)}{(a)}$ = % of capacity

RECOMMENDATIONS (cont)

Note that this check can be made most accurately if nearly all of the fuel is consumed in flight. When a large amount of fuel must be drained much of the accuracy is lost. The most accuracy is obtained if the airplane is flown until the fuel low level warning lite comes on and a landing is made immediately thereafter. The fuel counter generally is reading below zero when the low level light comes on. This test has actually been made a number of times.

Also note that this check is based on actual fuel capacity which is generally greater than the nominal 1335 gallon full internal capacity. Since all airplanes vary somewhat in capacity this additional usable fuel is not shown on the counter, however, it is available in an emergency.